Cost/Performance Benefits of Multi-Tasking on Intel Architecture Multiprocessor Workstations

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"One advantage of] a dual processor workstation is to be able to do true multi-tasking. We can run two programs at one time. We can be running Pro/ENGINEER* and we can be running another package that processes the data from Pro/ENGINEER, and there is a definite productivity gain."

David Moriconi, President, IDE Corporation
Speaking about Dual Processor Workstations Based on the Intel Architecture

ABSTRACT

This paper presents several examples of performance improvements available to users of multi-processor workstations based on the Intel Architecture; it focuses specifically on the benefits of multi-tasking. Multi-threading and multi-tasking are defined along with a methodology for measuring the potential performance improvement available in multi-tasking solution scenarios. Next, results from several performance tests are presented (an appendix provides additional detail on these tests) followed by a representative price comparison of workstations (pricing at the time of publication). Lastly, the paper presents a formula for calculating the time it takes to justify the acquisition of an incremental, second processor. The paper concludes that multi-processor Intel Architecture workstations offer a dramatic, cost-effective performance improvement over single-processor workstations.

INTRODUCTION

This paper discusses the productivity gain available today to users of multi-processor workstations based on the Intel Architecture. It specifically focuses on the performance and productivity improvement available through *multi-tasking* – the execution of multiple single-threaded applications over the multiple processors on a workstation. Other Intel documents address the benefits of running multi-threaded applications on Intel workstations.

Multi-tasking represents a significant opportunity to workstation users. Increasingly, customers are purchasing multi-processor workstations with multi-tasking in mind. This is reflected in an IDC study from May 1997 in which multi-tasking is cited by 63% of their survey as the primary reason for purchasing a multiprocessor workstation.

Workstations based on proprietary RISC architectures have been and remain relatively expensive. Because of this expense, multi-processor RISC workstations were usually reserved for *multi-threaded* high-end applications – applications specially developed to run multiple parts of an application simultaneously over available processors.

Workstations based on the Intel Architecture have changed the economics of multi-processing. With more and more Intel Architecture workstations in use, interest in and availability of multi-threaded applications is growing as standards-based development tools, operating system enhancements, system management and other tools have come to market.

Not all applications can be threaded or benefit from threading. Performance gains depend directly on the parts of the application that can be run in parallel. If that fraction is low, there may be little or no benefit from threading such applications.

There are, however, a number of solution scenarios involving multiple single-threaded applications that return tremendous benefit when run on multiprocessor workstations based on the Intel Architecture. These scenarios are typically made up of a number of applications which, taken together, represent a complete application solution to the workstation user. As mentioned above, the multi-processor workstation is executing multiple tasks on the available processors to improve productivity.

This paper presents some of these multi-tasking scenarios and provides information to help workstation users identify opportunities for productive use of multiprocessor workstations based on the Intel Architecture.

MEASURING MULTI-TASKING WORKLOADS

Before reviewing test results, we should review some fundamentals that went into designing the multi-tasking workloads. A fundamental rule in all benchmarking is that variation in testing must be constrained to a single variable – the one that is being measured. Typically one measures either the amount of time taken to perform a fixed amount of work or the amount of work that can be performed in a fixed amount of time. In a multi-tasking benchmark, this means that the measurement must encompass all of the tasks that comprise the benchmark. Although the tests presented here may not directly reflect the way in which a single user may use workstations, they were designed to accurately measure the potential benefit of multiple processors and to maximize the usefulness of the information provided.

All of the tests cited in this document present benchmarks measuring the duration of a constant workload, consisting of two tasks of similar duration. Workloads consisting of unequal tasks are not inherently bad, but can conceal the extent of the benefit achievable through the use of multiple processors. For this reason the tests and results presented below have been chosen to minimize single-task ‘tails’ – a job or task in a multi-tasking workload that continues to run after other jobs or tasks have completed – thus presenting a more generally useful measure of the benefit of multi-tasking on multi-processor workstations.

Consider a simple, hypothetical example consisting of two single-threaded tasks. When run *sequentially* on an uni-processor workstation, the first task may take 30 seconds and the second, 60 seconds. When both are run *simultaneously* on an uni-processor workstation, the first task may take 60 seconds to complete and the second, 90 seconds because the two tasks share a single processor. When run *concurrently* on a dual-processor workstation – one task on each processor – each takes about the same time to run as when run sequentially on the uni-processor configuration. Each runs in about 30 and 60 seconds, respectively, because the operating system is managing *concurrent* execution of the two tasks over two processors. In both the *simultaneous* uni-processor and *concurrent* dual-processor cases, the second task continues to run after the first has completed. It represents a single-task *tail* that runs for 30 seconds after the first task has completed. Since the second task is single-threaded, it can utilize only one processor. On the dual-processor workstation, the second processor is effectively idle for the last 30 seconds of the test. The resulting scaling ratio for the complete workload (comparing uni-processor and dual-processor results) is 1.5. The length of the single-task tail (30 seconds in this example) affects this ratio – the longer the tail, the closer the scaling ratio will be to 1.0. To get the most accurate measure of the potential benefit of a dual-processor workstation, the workloads should be adjusted to be of approximately equal duration.

Like any industry-standard benchmarks, the results presented here can only approximate a typical working environment. Results in specific work environments will vary.

EVALUATING PERFORMANCE

A series of six test were run to measure the benefit of dual-processor Intel Architecture workstations. Each test is described in detail later on in this document. Tests were run on Intel Architecture workstations fitted with either one or two Intel Pentium® II Xeon™ processors. The results in the chart below are expressed as a ratio of the time the benchmark takes on an uni-processor workstation versus a dual-processor workstation. A ratio of 2.0 represents the theoretical maximum. If there was no performance gain from the second processor, the resulting ratio would be 1.0.

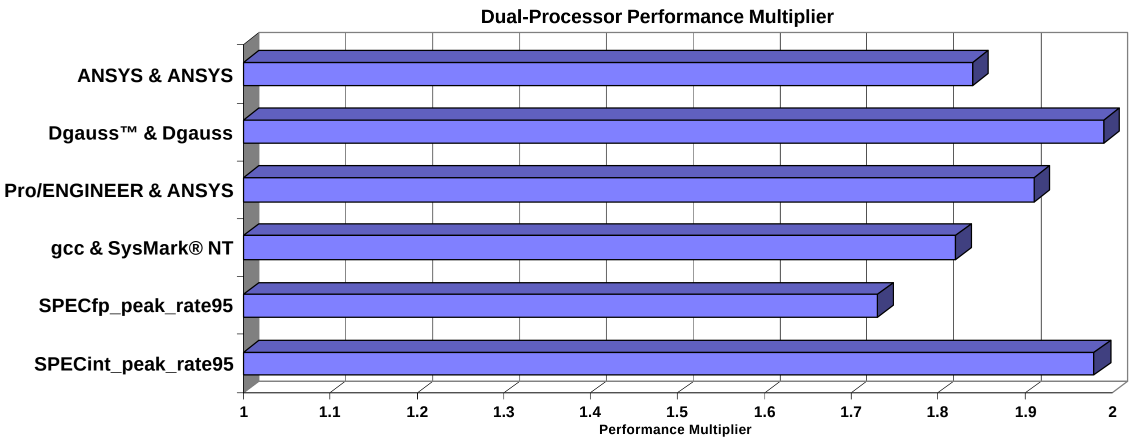

Figure 1 Bar chart summarizing the multi-tasking performance multiplier in six tests

Multi-Tasking Test Case Elapsed Time (seconds)	Uni-Processor	Dual-Processor	Performance Multiplier
Ansys 5.4 ttns-fs + Ansys5.4 ttns-fs	479.4	260.7	1.84
Dgauss Si3 + Dgauss Si3	3,485.7	1,752.3	1.99
Pro/E Bench97 + Ansys5.4 ttns-fs	2,946	1,544	1.91
SPEC*int95 gcc + Microsoft PowerPoint	200.2	110.3	1.82
SPECfp_peak_rate95	119.6	206.8	1.73
SPECint_peak_rate95	146.7	290.8	1.98
Average Performance Multiplier			***1.88***

Table 1 Table summarizing the multi-tasking performance multiplier in six tests

The data in the above chart and table illustrates the performance and therefore the productivity gains through the use of a second processor. In these benchmarks, the performance multiplier was 1.88, on average. Stated differently, the additional processor made it possible to run these workloads in about 53% of the time required on uni-processor configurations. This is a time savings of about 47%.

No programming changes were made to the applications tested and no system tuning was done to achieve these results. The performance information presented above suggests that workstation users running multiple compute-intensive applications can realize significant productivity gains by using dual processor workstations.

COMPARING COSTS

The relative and absolute results of these tests are remarkable in and of themselves. They are even more compelling when one considers the cost of a dual-processor Intel Architecture workstation. Only a few years ago, configuring workstations with multiple processors was a very expensive proposition. To provide such a configuration simply for multi-tasking would have been unthinkable.

Intel Architecture workstations have changed that. The table below takes a snapshot in time (May 1998) and presents estimated street prices for dual processor workstations. (Readers should check with their preferred vendor of Intel Architecture workstations for current prices.)

Vendor	Model	Processor Speed	Dual Processor System Price (Est. Street Price)
Major RISC-based Workstation Vendor	Dual Processor, 3D Graphics	300 MHz	$19,300
		360 MHz	$21,150
	Dual Processor, 3D Graphics	300 MHz	$24,725
		360 MHz	$26,575
Major Intel Architecture Workstation Vendor "A"	Dual Processor, 2D Graphics	333 MHz	$7,377
		400 MHz	$7,676
	Dual Processor, 3D Graphics	333 MHz	$8,327
		400 MHz	$8,626
Major Intel Architecture Workstation Vendor "B"	Dual Processor, 2D Graphics	333 MHz	$7,679
		350 MHz	$7,925
		400 MHz	$8.520
	Dual Processor, 3D Graphics	400 MHz	$9,438
Major Intel Architecture Workstation Vendor "C"	Dual Processor, 2D Graphics	333 MHz	$8,131
	Dual Processor, 3D Graphics	333 MHz	$12,216

Table 2 Estimated Street Prices for Dual Processor Workstations, May 1998

Note: Prices are approximate. Intel Architecture vendor pricing is for workstations based on the Pentium II processor; pricing for workstations based on the Pentium II Xeon processor was not

available at the time of publication. Data was gathered from public web sites, workstation manufacturers and/or their distributors. All configurations include 512 MB memory, 21-inch monitor, local hard drive and a network card. Some configurations include sound systems (card, speakers). 2D and 3D graphics configurations and capabilities vary.

COST JUSTIFICATION MODEL

Another way to view pricing is to compare performance benefits against the cost of a second processor. Whether you are adding a second processor to an existing workstation or considering the incremental cost of purchasing a dual processor vs. a uni-processor workstations, the example below shows that Intel Architecture workstations are remarkably productive and affordable.

In a hypothetical case, a workstation-based engineer spends approximately 40% of his/her time in meetings, preparing and reading reports, keeping up on mail, responding to various interrupts and addressing other day to day necessities of modern office work. Some of this time may well include time at the workstation – reading and replying to mail, for example. Of the balance, he/she spends 40% for engineering work – analysis, test preparation, writing code, and ‘think-time’ required to address the issues and opportunities of the task at hand. This 40% also includes time at the workstation for work that is well addressed by an uni-processor workstation. In this case, let’s assume that 20% of his/her time – one day per week – is spent at the computer doing the kind of work that could benefit from a dual processor configuration (multi-tasking of multiple jobs or running multi-threaded applications). As we have seen, on average, our dual-processor multi-tasking tests ran in about 53% of the time it took to run the same applications on an uni-processor workstation – a timesaving of 47%.

The time saved by the engineer is 47% of the 20% of his/her time applied to situations where multi-tasking would benefit, or 9.4% of his/her total work time. If we assume that the fully loaded cost of our engineer is $130,000, 9.4% translates to savings of $12,220 per year.

Actual prices will vary but assuming the cost of an incremental processor in an Intel Architecture workstation is approximately $1,000, the cost of the second processor is easily justified in about a month in this case. To be more specific, if we assume 240 workdays per year, the savings translates to $50.92 per day. Dividing the price of the additional processor ($1,000) by this daily savings ($50.93) suggests the second processor pays for itself in about 20 workdays – 4 workweeks.

As noted earlier, individual experiences may be different and users should analyze and understand their own specific requirements. In situations where multi-tasking opportunities are more plentiful and the workstation is used more than the one day per week in the above example, the payback is even faster.

There are many ways of calculating time-to-payback. The approach above is summarized in the following equation, which is also exemplified using the hypothetical case above. The example calculates time-to-payback assuming 240 workdays per year.

$$J = \frac{P}{(S * T * F)/WD} \qquad 19.64\,days = \frac{\$1{,}000}{(.47 * .20 * \$130{,}000)\ /\ 240}$$

Where:

J	=	Time, in days, to justify the purchase of a second processor
P	=	Price of the add-on or incremental processor
S	=	Percentage (proportion) of time saved, dual processor over uni-processor
T	=	Percentage (proportion) of time in which dual processors would be of benefit
F	=	Fully loaded annual cost of an engineer (pay, benefits, etc.)
WD	=	Workdays per year

CONCLUSION

In situations where multiple compute-intensive applications can be run in a near-simultaneous time frame, dual-processor Intel Architecture workstations offer a dramatic performance improvement over single-processor workstations. Intel Architecture workstations supporting dual processors are widely available, generally at a much lower price-point than similarly configured RISC workstations. When one considers the performance enhancement in light of the cost for a second processor, either as processor upgrade or when purchasing a new system, the value of multi-tasking with Intel Architecture multi-processor workstations is clear and readily justified by improved productivity.

APPENDIX: BENCHMARK SPECIFICATIONS AND DATA

The tests in this document represent scenarios that exercise the Intel Architecture workstation with two concurrent compute intensive jobs. All of the workloads have been carefully chosen so that their compute-intensive components are of approximately equal duration, thus giving the truest picture of the potential benefit of the second processor.

The specific test configurations are described below. The uni-processor tests were performed with only one processor physically in the system, and an uni-processor configuration of Windows NT* 4.0. A second processor was added to the same machines for the dual-processor tests, and the dual-processor configuration of Windows NT 4.0 was installed. No other changes were made to either software or hardware configurations.

All test results are the elapsed time for the complete workload, measured in seconds. Lower numbers represent faster completion of the workload and hence better performance.

Pentium® II Xeon™ Processors 400 MHz

All tests were run on workstations incorporating the new Intel Pentium II Xeon processor 400 MHz, using industry-oriented workloads and one familiar industry standard benchmark. The following system configuration was used for these tests:

Hardware	Component
Motherboard	MS440GX
PBA	AA 681940-504
BIOS	4D4KL0X0.86A.0016.P07
processor(s)	Pentium® II Xeon™ Processor 400 MHz
Memory	512 MB SDRAM
Disk	Seagate Cheetah 4LP, 10K RPM, 4.55 GB
Disk Controller	Adaptec 2940UW SCSI
Graphics Card	AccelECLIPSE (except for the SPEC® & SYSmark® for Windows NT4.0 .ppt test which uses a Matrox Millenium II
Networking card	Intel Pro 100B
Software	**Component**
Operating System	Window NT V4.0 SP3

Table 3 Configuration of Pentium® II Xeon™ Processor based workstations

ANSYS5.4 - TTNS-FS

Here we ran a test using the ANSYS* finite element analysis software. The ttns-fs benchmark operates on flood tank and tubes modeled with 3-D thin shell elements. It uses the frontal (Gaussian) equation solver, and has 10,000 to 50,000 degrees of freedom, which refers to the number of equations being solved. It produces a time-history solution for temperature, accounting for temperature-dependent thermal material properties.

ANSYS + ANSYS

	Uni-Processor	Dual-Processor	Performance Multiplier
Total Elapsed Time (Seconds)	466.6	249	1.87

Table 4 Multi-tasking test with ANSYS

Multiple copies of ANSYS ttns-fs were run on a dual processor workstation configured with 400 MHz Pentium II Processors. The time savings in this test was 47%, a performance multiplier of 1.87.

DGAUSS* - SI3

Oxford Molecular Group* (www.oxmol.com) is a leading supplier of software and services for discovery research with computational chemistry, with software installed at all the major chemical and pharmaceutical companies. Their Dgauss product is a quantum chemistry program used for studying electronic, magnetic, and structural properties of molecules and clusters application and was originally developed for Cray* supercomputers.

The workload used in this benchmark computes the energy and forces of a zeolite fragment, Si8O7H18. There are two portions to it: SCF and Gradient calculations. Each has three components. What is reported is a sum of all the run times.

DGauss + DGauss

	Uni-Processor	Dual-Processor	Performance Multiplier
Total Elapsed Time (Seconds)	3,439.8	1,734.3	1.98

Table 5 Multi-tasking test with Dgauss

Multiple copies of Dgauss Si3 were run on a dual processor workstation configured with 400 MHz Pentium II Processors. The time savings in this test was almost 50%, a performance multiplier of 1.98

PRO/E V18 - BENCH97 AND ANSYS5.4 – TTNS-FS

Pro/ENGINEER*, from Parametric Technology Corporation* (www.ptc.com) is a suite of integrated software products that automate the mechanical design-through-manufacturing process.

The benchmark tests advanced capabilities of Pro/ENGINEER such as holes, chamfers, rounds, and attachment hardware. The goal is to test a cross section of tasks and operations that make up a true work environment. As a result, the benchmark measured 69 tasks including those only performed occasionally such as plotting PostScript files and creating exploded views, as well as more frequently executed tasks such as model spinning, panning or zooming, and rotation.

ANSYS ttns-fs is the same benchmark described above.

Pro/E Bench97 + ANSYS

	Uni-Processor	Dual-Processor	Performance Multiplier
Total Elapsed Time (Seconds)	2,839.5	1,477.3	1.92

Table 6 Multi-tasking test with Pro/Engineer Bench97 and ANSYS

The table above presents results of the multi-tasking test in which the Pro/Engineer Bench97 benchmark and ANSYS ttns-fs analysis were run on a dual processor workstation configured with 400 MHz Pentium II Processors. Six iterations of Ansys5.4 ttns-fs were used to balance the workload. The time savings in this test was 48%, a performance multiplier of 1.92.

SPECINT95 - GCC, AND SYSMARKNT4.0 PPT

SPEC95 is a software benchmark product produced by SPEC*, the Standard Performance Evaluation Corporation, (www.specbench.org/) a non-profit group of computer vendors, system integrators, universities, research organizations, publishers and consultants throughout the world. It provides measures of performance for comparing compute-intensive workloads on different computer systems. SPEC95 consists of two suites of benchmarks: SPECint95 for measuring and comparing compute-intensive integer performance, and SPECfp95 for measuring and comparing compute-intensive floating-point performance.

The gcc component of SPECint95 consists of the GNU C compiler converting C preprocessed files into optimized SUN-3 assembly code.

SYSmark* for Windows NT4.0 is a suite of application software and associated benchmark scripts. They have been developed by BAPCo, the Business Applications Performance Corporation (www.bapco.com), in order to provide a tool for accurate and realistic measurement of system performance of personal computers running popular business-oriented applications in the Windows NT4.0 operating environment.

SPEC*int95 gcc + Microsoft* PowerPoint*

	Uni-Processor	Dual-Processor	Performance Multiplier
Total Elapsed Time (Seconds)	189.8	105	1.81

Table 7 Multi-tasking test with SPECint95 gcc compile and SYSMarkNT4.0 ppt

The table above presents results of the multi-tasking test in which a gcc compile was run with a SYSMarkNT4.0 benchmark on a dual processor workstation configured with 400 MHz Pentium II Processors. The time savings in this test was 45%, a performance multiplier of 1.81.

SPEC_RATE

Where as SPECint95 and SPECfp95 measure compute-intensive performance, SPECrate is a capacity measure. It is not a measure of how fast a system can perform any task; rather it is a measure of how many of those tasks that system complete within an arbitrary time interval.

To use an analogy, imagine that this is not about computers, it is about cooking stoves. If SPECint95 and SPECfp95 measures how fast one burner brings one cup of water to a boil, SPECrate measures how much water can be boiled by that stove (using whatever number of burners available). If a simple single-burner stove could boil one cup of water in 5 minutes, then it would have a rate of 12 cups an hour. If a four-burner stove could bring four separate cups of water to boil all in 15 minutes, it would have a rate of 16 cups an hour. The second stove would have a greater capacity, i.e. a higher SPECrate, but the first stove would be better for boiling an individual egg due to its better single-burner performance.

The tests were run with switches set to enable peak performance, thus the "_peak_" designator in the name of each test.

SPECfp_peak_rate95

	Uni-Processor	Dual-Processor	Performance Multiplier
Total Elapsed Time (Seconds)	119.57	206.81	1.73

Table 8 Multi-tasking test based on SPECfp_peak_rate95

SPECint_peak_rate95

	Uni-Processor	Dual-Processor	Performance Multiplier
Total Elapsed Time (Seconds)	146.7	290.80	1.98

Table 9 Multi-tasking test based on SPECint_peak_95

Website References

- **Intel**
  http://www.intel.com
- **SPEC results are available at:**
  http://www.specbench.org/osg/cpu95/results/results.html
- **BAPCo SYSmarkNT4.0 results are available at:**
  http://www.bapco.com/ntrslts.htm
- **ANSYS**
  http://www.ansys.com/VisitAnsys/Pubs/AnsysNews/Q4/page20/page20_partn.html
- **Dgauss: Oxford Molecular Group**
  http://www.oxmol.com
- **Pro/ENGINEER**
  http://www.proe.com
- **Sun Microsystems, Inc.**
  http://www.sun.com/
- **Hewlett-Packard Co.**
  http://www.hp.com/
- **International Business Machines**
  http://www.ibm.com/
- **Dell Computer Corp.**
  http://www.dell.comm/
- **Silicon Graphics**
  http://www.sgi.comm/
- **Gateway 2000**
  http://www.gateway2000.comm/
- **NEC**
  http://www.nec.comm/
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